

TRANSPARENT HEAVY MINERAL DISTRIBUTION IN THE BAYS OF JAIGAD, AMBWAH, AND VARVADA, RATNAGIRI DISTRICT, MAHARASHTRA

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Abstract

Transparent heavy minerals exhibit a variety of textural features from highly euhedral to rounded. Grains of a few minerals like kyanite, tourmaline, epidote and zircon have shown overgrowth, cavities due to solution activities and depressions of etching marks. On the basis of the abundance of a particular mineral three distinctive assemblages of heavy minerals, each specific to a particular bay, are recognised, namely, olivine-pyroxene assemblage for the Jaigad Bay, zircon-kyanite-olivine-pyroxene assemblage for the Ambwah Bay and tourmaline-zircon-kyanite assemblage for the Varvada Bay. Epidote and topaz are found common to all the bays. The earlier works projected the provenance of Deccan basalts to the beach placers. However, a mixture of source rocks has now been considered. Three types of tourmalines, i.e., brown, bluish green and rarely yellow, prismatic to rounded with occasional fluid inclusions, are present. They are typical derivatives of pegmatites. The bluish green hornblende typifies the origin from high rank metamorphic rocks. The ultra stable minerals like zircon, tourmaline and smooth kyanite suggest long transportation from earlier sediments and subsequent recycling or reworking, and probably entrapment of the minerals in the surf zone. The presence of overgrowth with sharp edges in zircon and kyanite bring out the long stay in the depositional basin, giving way to intrastatal solution activities. Different kinds of zircon indicate the supply from quartzites, high rank metamorphics, earlier sediments and granitic sources.

Introduction

In connection with the offshore placer mineral exploration, an area of 24.3 sq km in the Jaigad Bay, 8.59 sq. km in the Ambwah Bay and 4.02 sq.km in the Varvada Bay was surveyed. The sampling was done using a Van-Veen grab in a grid pattern, keeping an interval of about 200 m between the grids. It was continued upto the close of sandy bed. Nearly 296 samples were collected for heavy mineral distribution.

The occurrences of ilmenite on the beaches of the Ratnagiri coast have been described by Krishnan and Roy (1945) and Roy (1958). The heavy mineral placers on the beaches are expected to extend to offshore areas and some placers may also be associated with the lower sea level strands during the Pleistocene. Extension of such placers to offshore areas has been reported by Siddiquie (1975). Subsequently, Siddiquie and Rajamanickam (1979) in a review of the surficial mineral deposits on the continental shelf of India have described the preliminary results of the surveys for heavy mineral placers of Ratnagiri. Siddiquie and Rajamanickam (1979) have brought out the nature of offshore ilmenite placers emphasising their economic value. However, no detailed study has been undertaken on the distribution of transparent heavy minerals and their provenance. In the present study an attempt is made to picturise the nature of the provenance by studying the optical characters of such minerals in the sediments of Jaigad, Ambwah and Varvada bays (Fig. 1).

Methodology

The sediment samples are washed in the laboratory to remove salt etc., dried and sieved to standard mesh sizes to separate them into sand, silt, and clay fractions. The sand and silt fractions are separated

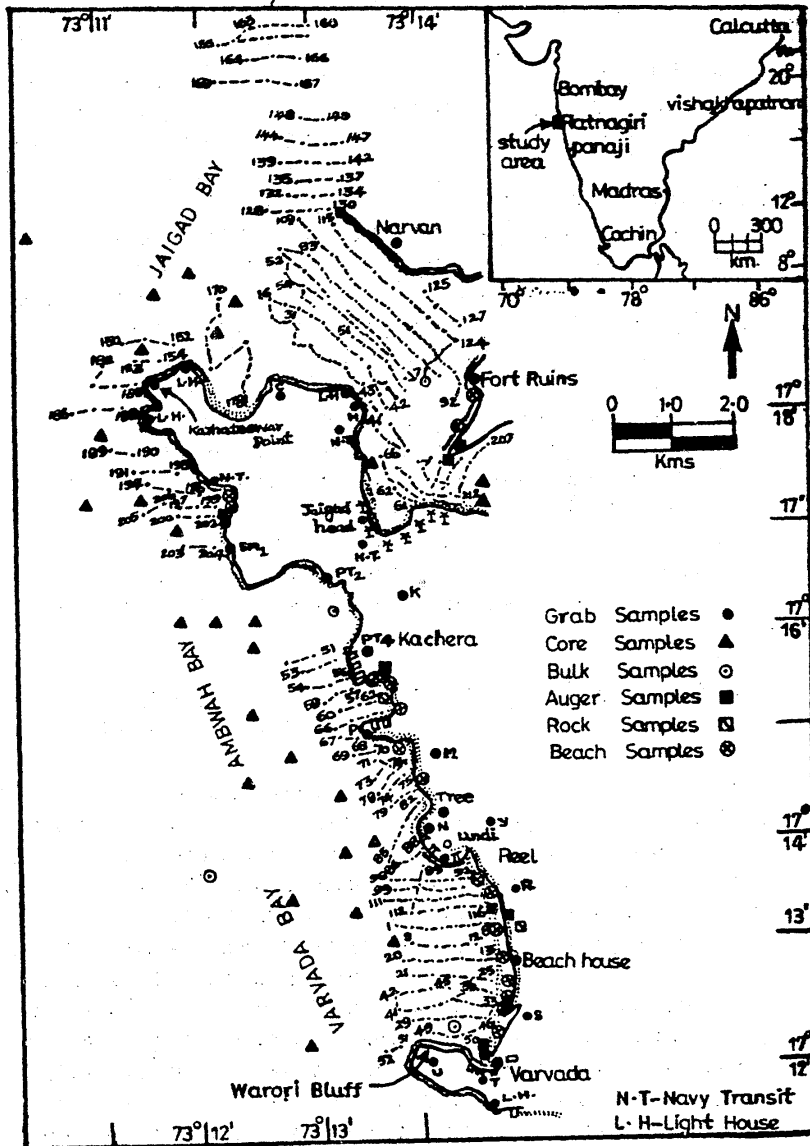


Fig. 1. Map Showing the Sample Locations and Study Area

into heavy and light minerals using bromoform (specific gravity 2.89). The heavy mineral fractions are further separated on a Cook's Magnetic Separator into magnetic and non-magnetic fractions. The initial magnetic separation is being carried out at the lowest magnetic intensity and on a vertical feed, so as to enable a separation on an inclined feed in the same magnetic separator into ilmenite and other minerals, i.e., hornblende, augite, and diopside, etc. Selected samples of heavy minerals are mounted in Canada balsam and examined under the microscope. The initial sand and silt samples and the various separated fractions are weighed, and the results expressed as weighed percentages.

Distribution of Heavy Minerals

Heavy minerals include both opaque and transparent mineral assemblages. The distribution percentage of total heavy minerals is shown in Fig. 2, which indicates a low percentage zone in the middle of the Ambwaha Bay, where there is no direct sediment supply. The presence of higher concentration of heavies in the mouth of the Varvada creek is due to strong winnowing. The lighter fractions removed from this area due to winnowing would have been deposited or drifted to the adjoining beach by waves, causing a dilution of the heavier concentration all along the near shore of the Ambwaha Bay. The increased concentration of heavy minerals in the northern part of the Varvada Bay, that is off Undi, is probably the result of the convergence of the waves at this point as well as the winnowing by the southwesterly monsoonal waves. Though large amount of sediments are being deposited at the confluence of the Shastri River in the Jaigad Bay, the concentrations of heavy minerals are found to be lesser here than in the Varvada Bay. The Shastri River channel has shown a poor concentration of heavier fractions, possibly owing to the high current activities forbidding the deposition of finer sands in which the heavy minerals are expected to be more concentrated. An appreciable increase of heavy mineral percentage in the northeastern part of all the bays suggest the possibility of strong winnowing action during the southwesterly monsoonal period.

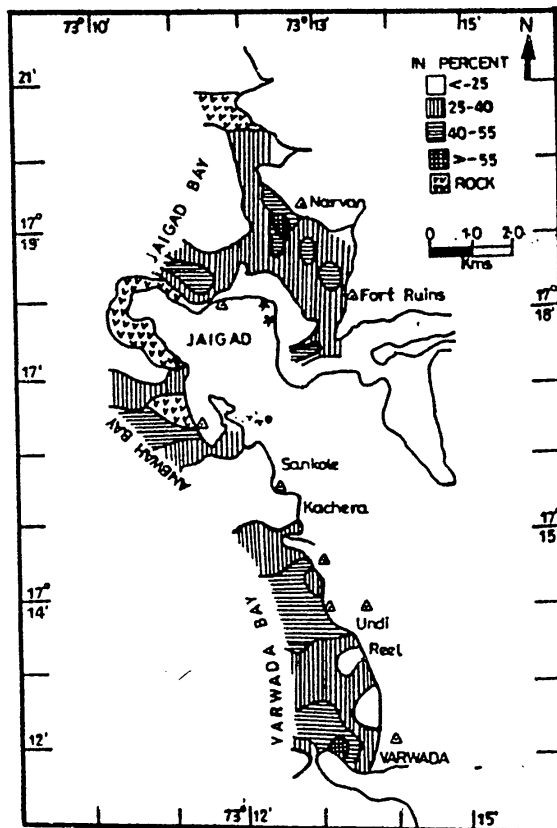


Fig. 2. Distribution of Heavy Minerals in the Investigated Area

Preparation of Samples for Counting

A part of the separated non-ilmenite fraction was removed by coning and quartering and mounted on a glass slide with Canada balsam. Care was exercised to see that at least three hundred non-opaque grains are included in each mount. In order to estimate the required quantity for mounting, a part of the sample beforehand was scanned through a binocular microscope to determine the approximate ratio between non-opaque to opaque grains. With a view to avoiding error due to number frequency and number percentage, as suggested by Galehouse (1969), grains of uniform size of 0.088 mm to 0.074 mm in diameter (-170 to +200 mesh) were selected for mounting. Three tracks of each bay and three samples from each track representing the near-, middle-, and offshore-zones were selected for counting of the grains by using a mechanical stage. Mineral number percentage for each of the constituent minerals was obtained by ribbon traverse counting method (Van der Plas, 1962).

Results and Discussion

Sixteen transparent heavy minerals have been identified. In the individual percentage in different bays is shown in Tables 1, 2, and 3 (Fig. 3). In addition to the transparent minerals, the sample contains significant quantities of opaque grains, whose mineralogy and textural characteristics are discussed elsewhere.

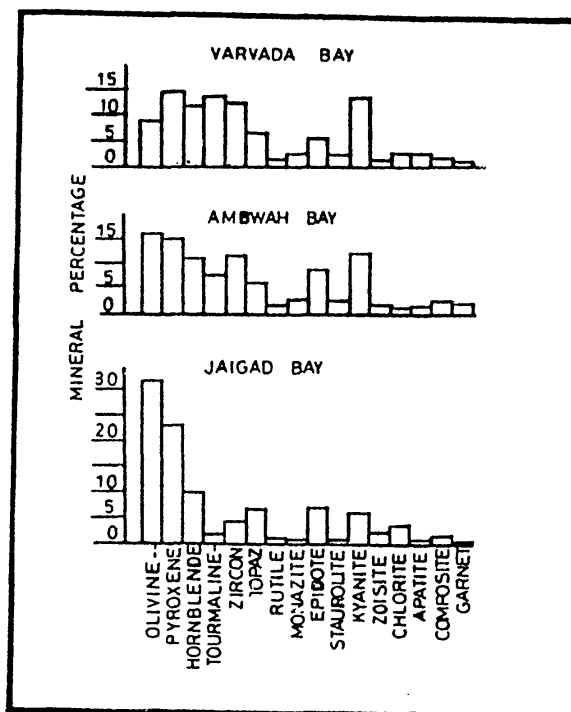


Fig. 3. Average Mineral Percentage Variation of Non-opaque Heavy Mineral in Jaigad, Ambwah and Varvada Bays

TABLE 1: PERCENTWISE DISTRIBUTION OF TRANSPARENT HEAVY MINERALS IN JAIGAD BAY

| Name of the Mineral | Sample Numbers | | | | | | | | | | | | Average | |
|---------------------|----------------|------|------|------|------|------|------|------|------|------|------|------|---------|------|
| | J18 | J15 | J12 | J10 | J8 | J5 | J2 | J209 | J104 | J94 | J75 | J146 | | J147 |
| Olivine | 36.2 | 32.0 | 40.9 | 27.0 | 37.0 | 31.0 | 30.0 | 32.8 | 32.0 | 30.0 | 23.4 | 33.0 | 26.2 | 31.6 |
| Pyroxene | 27.6 | 27.6 | 22.6 | 22.0 | 28.0 | 22.0 | 25.0 | 23.0 | 17.4 | 19.4 | 20.4 | 21.0 | 21.0 | 22.8 |
| Hornblende | 7.1 | 14.7 | 6.0 | 21.0 | 7.0 | 12.0 | 2.0 | 14.9 | 8.6 | 4.8 | 16.0 | 7.0 | 9.6 | 10.1 |
| Tourmaline | 0.9 | 1.6 | 2.0 | 2.0 | 1.6 | 0.5 | 4.0 | 1.0 | 1.2 | 1.3 | 3.0 | 2.0 | 2.0 | 1.8 |
| Zircon | 2.4 | 6.9 | 4.8 | 2.0 | 5.0 | 3.0 | 7.0 | 3.4 | 5.4 | 3.2 | 6.0 | 3.0 | 7.0 | 4.5 |
| Topaz | 5.5 | 3.4 | 4.8 | 5.0 | 4.0 | 7.0 | 9.0 | 2.7 | 10.2 | 14.5 | 9.0 | 3.0 | 9.6 | 6.7 |
| Rutile | - | 0.9 | - | 1.0 | 0.8 | 0.5 | 2.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 0.9 |
| Monazite | - | - | - | 1.0 | 0.8 | - | - | 1.0 | 1.0 | - | 1.0 | 0.5 | 1.0 | 0.5 |
| Epidote | 7.9 | 5.2 | 4.2 | 7.0 | 5.0 | 8.0 | 8.0 | 6.1 | 8.5 | 11.3 | 6.5 | 8.0 | 6.0 | 6.9 |
| Staurolite | 0.8 | - | - | - | 0.8 | 0.5 | - | 1.0 | 1.0 | - | - | 2.0 | 1.0 | 0.5 |
| Kyanite | 3.1 | 3.5 | 6.5 | 7.0 | 4.0 | 5.5 | 5.0 | 4.7 | 5.5 | 6.5 | 5.9 | 10.0 | 7.6 | 5.8 |
| Zoisite | 2.4 | - | 2.4 | 3.0 | 2.0 | 3.0 | 2.0 | 2.0 | 1.2 | - | 7.5 | 3.0 | 0.6 | 2.2 |
| Chlorite | 3.9 | 4.3 | 2.4 | 1.0 | 2.0 | 3.0 | 6.0 | 5.4 | 4.8 | 4.8 | 3.0 | 3.0 | 2.5 | 3.5 |
| Apatite | 1.0 | - | - | 1.0 | 1.0 | 0.5 | - | 1.0 | 1.5 | 1.5 | - | 0.5 | 2.0 | 0.8 |
| Composite | 2.4 | - | 3.6 | - | 1.0 | 3.0 | - | - | 1.0 | 1.0 | - | 3.0 | 1.0 | 1.2 |
| Garnet | 0.8 | - | - | - | - | 0.5 | - | - | - | 0.7 | 0.9 | - | 0.8 | 0.2 |

Olivine occurs as irregularly shaped and much fractured grains exhibiting strong polarisation colours, straight extinction with positive biaxial interference figure. Its grains are often found altered into bowlingite or iddingsite characterised by the presence of opaques along the parting and cleavage planes.

Three types of pyroxenes; namely, augite, pigeonite, and diopside, have been identified. Each is recognised by its typical colour, pleochroism, cleavage, extinction angle and high relief. Pyroxenes are commonly anhedral (Pl. 1:1) with high amount of opaque inclusions and alteration to either chlorite or hornblende. However, in some cases intense alteration of their grains has prevented correct measurement of the extinction angle.

TABLE 2: PERCENTWISE DISTRIBUTION OF TRANSPARENT HEAVY MINERALS IN AMBWAH BAY

| Name of the mineral | Sample Numbers | | | | | | | | | Average |
|---------------------|----------------|------|------|------|------|------|------|------|------|---------|
| | A81 | A77 | A62 | A63 | A65 | A16 | A30 | A2 | A199 | |
| Olivine | 12.8 | 9.2 | 13.1 | 12.0 | 11.0 | 21.8 | 28.1 | 14.9 | 21.9 | 16.1 |
| Pyroxene | 10.5 | 18.4 | 10.9 | 25.0 | 19.2 | 15.8 | 12.3 | 13.2 | 10.3 | 15.1 |
| Hornblende | 11.4 | 11.8 | 13.1 | 7.0 | 11.4 | 9.0 | 7.9 | 9.6 | 12.8 | 10.5 |
| Tourmaline | 9.0 | 7.9 | 14.9 | 7.0 | 9.5 | 5.7 | 2.6 | 4.4 | 6.0 | 7.4 |
| Zircon | 12.4 | 11.8 | 9.7 | 5.0 | 8.4 | 10.5 | 11.4 | 21.9 | 10.3 | 11.3 |
| Topaz | 5.2 | 6.6 | 8.0 | 3.0 | 2.0 | 7.5 | 8.8 | 7.9 | 4.3 | 5.9 |
| Rutile | 2.0 | 2.6 | - | 1.0 | 2.4 | 1.0 | 1.4 | 0.9 | 1.7 | 1.4 |
| Monazite | 3.5 | 3.3 | 2.3 | 4.0 | 4.5 | 2.0 | 2.6 | 1.8 | 0.9 | 2.8 |
| Epidote | 5.2 | 5.9 | 9.7 | 7.0 | 8.2 | 12.8 | 7.9 | 8.8 | 11.4 | 8.5 |
| Staurolite | 2.4 | 1.3 | 1.4 | 5.0 | 4.0 | 1.5 | 0.9 | 2.6 | 1.7 | 2.3 |
| Kyanite | 15.4 | 18.4 | 16.6 | 11.0 | 14.2 | 8.0 | 8.8 | 7.9 | 7.7 | 12.0 |
| Zoisite | 2.1 | 1.3 | 0.6 | 1.0 | 2.0 | 0.8 | 0.9 | 0.9 | 1.7 | 1.3 |
| Chlorite | 2.4 | 1.3 | - | 1.0 | 1.2 | 1.5 | - | 0.9 | 1.7 | 1.1 |
| Apatite | 2.4 | 2.6 | - | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 1.7 | 1.3 |
| Composite | 2.4 | 2.6 | - | 4.0 | - | 5.5 | 3.0 | - | 4.3 | 2.4 |
| Garnet | 1.0 | 2.0 | - | 6.0 | 1.0 | 0.7 | 2.6 | 3.5 | 1.7 | 1.9 |

TABLE 3: PERCENTWISE DISTRIBUTION OF TRANSPARENT HEAVY MINERALS IN VARVADA BAY

| Name of the Mineral | Sample Numbers | | | | | | | | | |
|---------------------|----------------|------|------|------|------|------|------|------|------|---------|
| | V48 | V47 | V22 | V23 | V27 | V2 | V5 | A105 | A94 | Average |
| Olivine | 10.3 | 8.0 | 7.7 | 9.5 | 8.4 | 10.5 | 8.0 | 9.7 | 13.9 | 9.1 |
| Pyroxene | 13.9 | 10.0 | 17.0 | 11.6 | 14.6 | 16.6 | 15.9 | 12.4 | 20.0 | 14.7 |
| Hornblende | 10.9 | 12.0 | 19.0 | 8.8 | 16.3 | 10.5 | 11.2 | 6.2 | 13.9 | 11.8 |
| Tourmaline | 14.5 | 20.0 | 12.8 | 13.5 | 10.2 | 8.4 | 13.4 | 13.3 | 13.0 | 13.4 |
| Zircon | 11.4 | 20.0 | 9.9 | 19.0 | 11.0 | 8.4 | 8.4 | 12.4 | 9.6 | 12.2 |
| Topaz | 5.6 | 5.0 | 4.9 | 6.4 | 4.2 | 6.3 | 8.4 | 13.3 | 3.5 | 6.4 |
| Rutile | 0.7 | 0.9 | 0.7 | 1.4 | 0.8 | 0.7 | 5.4 | 1.8 | - | 1.4 |
| Monazite | 1.4 | 2.0 | 1.4 | 2.0 | 0.8 | 2.8 | 2.1 | 4.4 | 3.5 | 2.3 |
| Epidote | 9.4 | 5.0 | 4.2 | 4.1 | 2.5 | 8.4 | 4.2 | 8.8 | 5.2 | 5.7 |
| Staurolite | 2.2 | 0.9 | 0.7 | 1.2 | 0.8 | 2.8 | 3.5 | 0.8 | 2.5 | 1.9 |
| Kyanite | 11.6 | 12.0 | 11.5 | 13.8 | 12.8 | 14.7 | 15.2 | 14.2 | 11.3 | 13.1 |
| Zoisite | 1.4 | 0.9 | 1.4 | 1.7 | 1.6 | 1.4 | 0.7 | 1.8 | 0.9 | 1.3 |
| chlorite | 1.4 | 0.9 | 2.1 | 3.4 | 6.6 | 4.4 | 0.7 | 0.8 | - | 2.3 |
| Apatite | 3.6 | 2.0 | 1.4 | 2.0 | 5.6 | 3.5 | 0.7 | 0.8 | 0.9 | 2.3 |
| Composite | 1.4 | 1.0 | 4.2 | 1.2 | 4.7 | - | 1.4 | - | - | 1.5 |
| Garnet | - | - | 1.4 | 0.6 | 0.8 | 0.7 | 0.7 | - | 1.7 | 0.6 |

Amphiboles are represented primarily by the normal type of hornblende. They are found in two colours of green and brown; the former predominating over the latter. They are acicular in habit and strongly pleochroic. Both the varieties are commonly altered to green chlorite and at times are marked with etching (Pl.1:2). Minute inclusions in them are also be seen.

Brown and bluish green varieties of tourmalines have been recognised. Its grains are prismatic (Pl.1:3) with some rounding at corners, although well rounded (Pl.1:4) to elliptical grains are not uncommon. The brown tourmaline occurs frequently with cavities (Pl.1:5) and with fluid inclusions along with those of opaque particles (Pl.1:6), zircon and rutile, while the bluish green variety is mostly fresh. The edges of the prismatic grains are somewhat etched.

Both colourless and pink varieties of zircon are noted. Zircon grains are elliptical to oval (Pl.1:7) and rarely euhedral in shapes (Pl.1:8). Some of them are characterised by overgrowths (Pl.1:9) thick shell (Pl.1:10), and zonal structures. The crystal edges are often rounded (Pl.1:11). Inclusions of micro-zircon, apatite needle, opaque dust and glassy fluid arranged parallel to the length of the crystal are present.

Topaz grains are irregularly shaped and are easily recognised by the bluish tinge on the fractured edges, positive interference figure and small 2V. They often contain fluid inclusions.

Rutile, an uncommon heavy mineral, occurs as elongated (Pl.1:12) and prismatic grains (Pl.1:13) with dark brown to reddish brown colour. It, at times, exhibits geniculate twinning with optic plane parallel to (110).

Monazite, although rare, occurs in well rounded grains in shades of pale yellow with dark border and high relief; inclusions of gas-filled cavities are not uncommon. Infrequently, monazite is found in deep brown colour becoming opaque when very dark.

Epidote forms angular (Pl.1:14) to subrounded grains of yellowish green pistachio variety, but many grains are colourless. Epidote is easily identified by the diagnostic bright green to purple-red ringed interference colours and by compass needle interference figure.

Staurolite is very rare. When present, it commonly has hackly fracture, and haphazard to concentric boundaries with pleochroism varying greatly from grain to grain. The mineral has abundant inclusions.

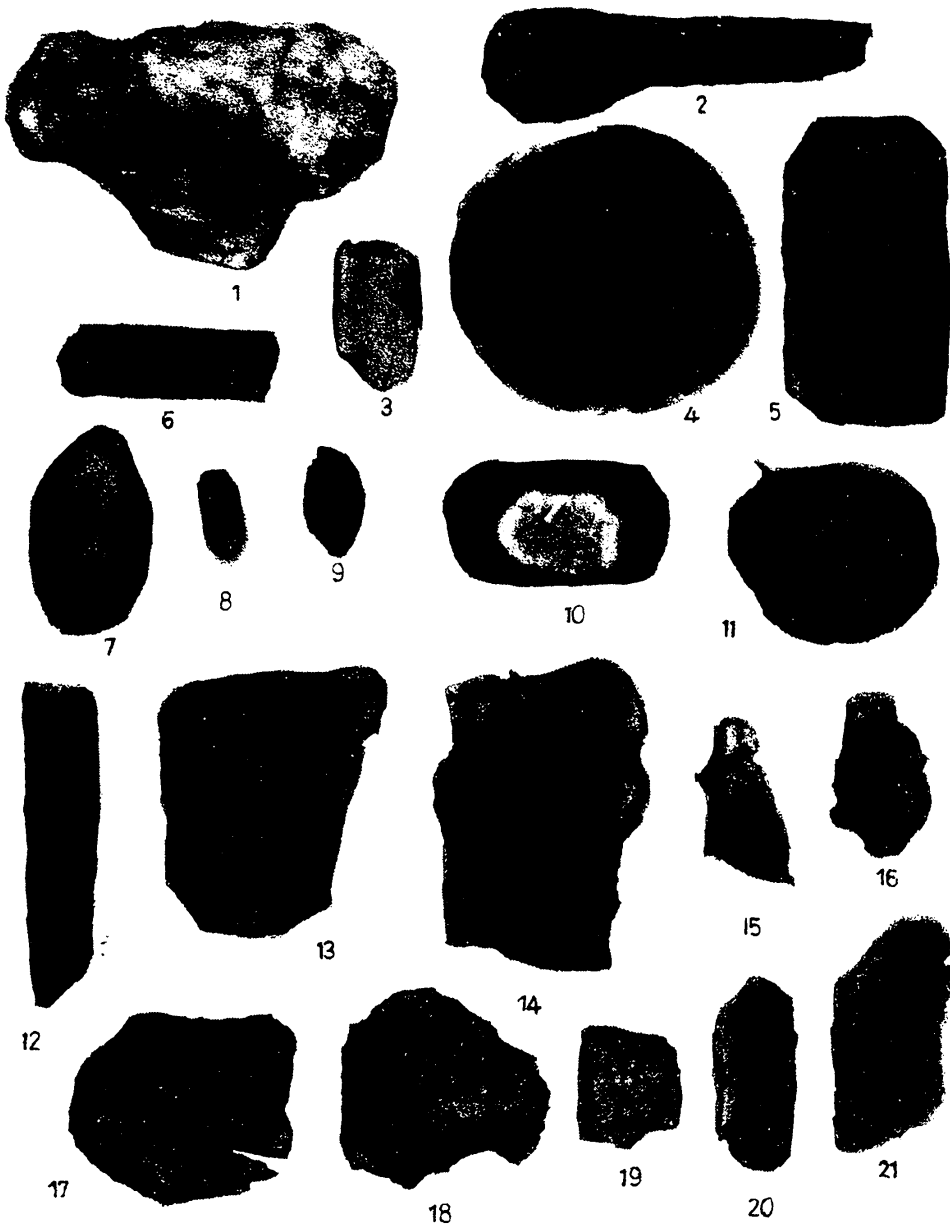


Plate 1. (250 X) 1. Anhedral Pyroxenes. 2. Altered Hornblende with Strong Etching Marks. 3. Prismatic Tourmaline., 4. Rounded Tourmaline. 5. Brown Tourmaline with Cavities. 6. Brown Tourmaline with Fluid and Opaque Inclusions. 7. Elliptical Zircon. 8. Euhedral Zircon. 9. Overgrown Zircon. 10. Thick shelled Zircon. 11. Rounded Zircon. 12. Elongated Rutile. 13. Prismatic Rutile. 14. Angular Epidote. 15. Kyanite Prismatic. 16. Frayed Kyanite. 17. Kyanite with Rounded Edges. 18. Kyanite with etching Mark. 19. Anhedral Zoisite. 20. Etched Chlorite. 21. Composite Grains

Kyanite forms elongate, irregular and prismatic grains of colourless to light blue colour. Some of its grains show short stumpy nature with more aberrations. Others are observed with overgrowths on the prismatic face (P1.1:15). Typically, frayed grains due to corrosion can also be seen (P1.1:16). Locally, the grains have rounded corners on prismatic grains (P1.1:17) and some are rounded showing conspicuous etching (P1.1:18).

Zoisite is rare, but when it occurs, it is anhedral (P1.1:19), colourless, and non-pleochroic, locally containing inclusions of light green amphibole (?). It can be discerned by moderate birefringence, specially the deep blue interference colours.

Chlorite is green or greenish yellow in colour, flacky in habit and displays ultrablue interference colour under cross nicols. Most of the grains are biaxial positive with isogyres showing well-marked dispersion. Locally it is also found with etching (P1.1:20).

Apatite develops small laths which, parallel to the prismatic edges are found to contain minute inclusions. At high magnification evidence of solution activities are observed. Besides forming independent grains, it also occurs as minute inclusions in other minerals.

Garnet with etched margins is of very occasional occurrence. Its surface sometimes gives pitted appearance and elsewhere reticulate appearance due to two directional cleavages.

Apart from the grains of individual minerals, there are also composite grains made up of opaque, semi-opaque and translucent minerals, possibly formed by cementation during transportation. Bisdorn and Riezebos (1978) have observed this kind of composite grains in the Roer River sands. Although composite grains in the examined heavies are very rare, such a grain when present may contain semi-opaque and transparent minerals adhering to each other (P1.1:21).

Provenance of Sediments

Related heavy mineral suite is commonly a diagnostic feature of the provenance of a sediment, specially when it comprises matured sand and lacks rock fragments and light minerals. Although some heavy mineral species may be selectively destroyed during transport and diagenesis, the survived tough and resistant minerals are the best indicators and sometimes the only guide to provenance of the related sediments. Hubert (1962) used chemically resistant like zircon, rutile and tourmaline (ZTR) index to interpret the maturity of the sediments. The heavy concentration of the bays have varying concentrations of different heavy minerals in different grain-size fractions of the sediments depending upon the hydraulic equivalence. Van Andel and Poole (1960) have shown the concentration of zircons only in the fine-grained sediments. Blatt and Sutherland (1969) have proved that the rate of the intrastratal solution is higher in coarse-grained sediments than the less permeable fine-grained sediments and such differential solution activities have increased the differences between heavy mineral suites in fine- and coarse-grained sediments derived from identical sources. Hand (1967) has used the differences in settling velocity of light and heavy mineral fractions to distinguish aeolian and beach sands. White and Williams (1967) found the differences in settling velocity of quartz and tourmaline in different parts of a cross-bed and found in its various elements differences in the mineral grain-ratios of traction to suspension during sedimentation. Before heavy minerals are utilised for deciphering provenance three conditions should be satisfied; that the grain size of the heavies in question is uniform, they are of similar hydraulic equivalence and also chemically stable. Satisfying these conditions heavy minerals have been used as the best criteria for determining the provenance by many workers such as (Van Andel and Poole, 1960; Davies and Moore, 1970; Bisdorn and Riezebos, 1978; Force, 1980; Beiersdorf, 1980 and Luepke, 1980).

Roy (1958) and Krishnan and Roy (1945) indicated that the black sand of Ratnagiri beaches are derived from trap-rock weathering. On the basis of mineralogical and geochemical data, Mukherjee and Saxena (1976) suggested Deccan traps as the source of the beach placers. Siddiquie and

Rajamanickam (1979) and Siddiquie *et al.* (1975) have attributed the Deccan basalts as the source of the offshore placers after a detailed survey of the Kalbadevi, Mirya and Ratnagiri Bays. Subba Raju and Rao (1978) have ascribed the Deccan traps and laterite exposed in the hinterland and as well as their sub-surface outcrops below the sands as the source rocks for the beach placers. The results of the present study of the author are not totally in consonance with the views of those expressed above. Although the role of the basalts in contributing material for the placer cannot be totally ruled out, the rocks of the earlier periods, which have been eroded and buried, also seem to have provided sediment constituents to the placers, and what is seen today is the mixture of the two.

The Transparent heavy minerals also clearly denote multi-source of the mineral constituents of the placers. The identified mineral assemblages when compared with the data of Pettijohn (1975) indicate the possibility of their having been derived from mafic and felsic igneous rocks and high grade metamorphic rocks. The hornblende of the sands is dominantly of bluish green variety which is considered to be of high rank metamorphic source rock. The presence of topaz, zircon, tourmaline, apatite, on the contrary, affirm the pegmatitic source of these minerals. Three types of tourmaline are recognised: brown, bluish green and rarely yellow; all the varieties occur in short prismatic to rounded grains with occasional fluid inclusions. On comparison of their textural and mineralogical characters with the varieties of Krynine (1946), they appear to be derivative of meta-psammites such as quartzites, and quartz-mica-schists, whereas the presence of olivine, which is normally not reported from the marine sediments, and augite-pigeonite are indicative of a mafic source. The olivines are usually considered to be unstable minerals (Pettijohn, 1975) and its presence in the basin in large amount with high angularity and freshness, therefore, is regarded due to high altitude, leading to quick dumping that protects their chemical instability and close by exposures of the source rocks which can avoid their long transportation and disintegration, none else but Deccan traps intending quick and short transport of the denuded material.

ZTR index (Hubert, 1962) of the sediments indicate their maturity. Within the three bays, the Jaigad Bay sediments show the presence of the least matured sands and those of Varvada are most matured. Variation in the degree of maturity of the sediments of the three localities can be explained by the simple fact, that in the Jaigad Bay the Shastri River dumps directly the recent sediments, and, hence, there is predominance of immatured sands in this bay. On the contrary, greater degree of maturity of sands in the other two basins, Ambwah and Varvada, appears to be due to their being located farther away from the recent sediment sources.

There can be any of the following determinants for the roundness of ultrastable minerals, like zircon and tourmaline, and the smoothness of kyanite corners: (1) Long transportation of sediments, (2) their derivation from the earlier sediments and subsequent recycling or reworking and final deposition in the basins, or (3) entrapment of the minerals in the surf zone and their tossing about before reaching the depositional basin.

The overgrowths observed in zircon and kyanite and the etching of the kyanite, hornblende, epidote and tourmaline suggest the role of intrastratal solution activities in the depositional basin. These grains might have remained in the bays longer than pyroxenes and olivines. Roundness of the margins of zircon grains indicate the possibility of their transport from the source after acquiring this feature or possibly of having sedimentary or parametamorphic source prior to acquisition of the feature.

By colour, zircons are of two types: pink and colourless. Mackie (1923) and Tomita (1954) have attributed the differences in colour of this mineral to different provenances and in the metasomatised gneisses of Purila Mahadevan (1968) considered them due to the different surges of solutions. Some zircon show colourless core with pink border, the former being irregular in shape, in some grains with c-axis inclined to that of the surrounding zircon corona. Such zircons have been attributed to a parametamorphic source, such as quartzites of the southern Konkan. Deshmukh (1968) and Ray

(1968) have also recorded only green and brown coloured varieties of zircons but from Deccan basalts: these zircons are euhedral to subhedral with effects of magmatic corrosion and they have not been observed in the sediments of the investigated area. However, euhedral colourless zircons have been noted and they seem to be of basaltic affiliation.

Tourmaline of different colours and shapes are also found in the studied sediments. These are of short prismatic habit and oval to rounded in shapes, that are indicative of either the distant source or recycled characteristics of the host sediments but not the product of the same rock, which yielded the short prismatic grains. The aforesaid oval to rounded tourmalines are presumed to be of distant source, probably sandstone, and the short prismatic possibly of either tourmalinised sediments or metamorphic rocks in which this mineral may occur without nucleation. These kinds of tourmaline of the author and the two types of zircon have also been noted by Wagle and Rajamanickam (1980) in the quartzites of the Goa coast situated to the south of the present area.

The results of the study on heavy minerals can be succinctly summarised as follows:

| <i>Mineral Assemblage</i> | <i>Possible Source</i> |
|--|---|
| Olivine, pyroxene, chlorite, composite grains, zoisite, epidote, apatite, rutile and brown hornblende | Deccan trap |
| Colourless zircon; brown, bluish green tourmaline; topaz and monazite | Distant Kaladgi sandstone, pegmatitised sandstone and Dharwar sediments (?) |
| Thick shelled colourless zircon, pink zircon, short prismatic and yellow tourmaline, topaz, apatite and green hornblende | Quartzites, Micaceous quartzites |
| Kyanite, staurolite and garnet | High grade metamorphic rocks |

Conclusion

The study of transparent heavy minerals of the sediments from the bays reveals marked differences in them by way of distinct mineral assemblages: olivine-pyroxene-tourmaline-zircon-kyanite assemblage is typical of the Ambwah sediments, and tourmaline-kyanite-zircon suite is present in the Varvada sediments. Mineralogical speculations including colour characteristics of tourmalines, kyanites, hornblende and zircons help predicting their source in high grade metamorphic and pegmatitic rocks and that of olivine and pyroxene mineral pair in basalts. The extreme roundness acquired by the highly resistant minerals such as tourmaline and zircons betray recycling of sediments rather than signs of long transportation.

Acknowledgements

The authors thank the Director, National Institute of Oceanography and the Director, Indian School of Mines, Dhanbad, for facilities, and Prof. O. P. Varma for his guidance and suggestions. The authors also thank their colleagues at NIO, Dr. M. V. Ramanna, Mr. Kotnala, Mr. M. C. Pathak and Mr. S. K. Nanniyasy for their help in the collection of samples.

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